Atomic Energy Control Board
P.O. Box 1046
Ottawa, Canada
K1P 5S9

Commission de contrôle de l'énergie atomique
C.P. 1046
Ottawa, Canada
K1P 5S9

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ANALYSIS OF QUALITY CONTROL TESTS DONE BY THE CANADIAN POWER UTILITIES ON THEIR EXTERNAL DOSIMETRY SYSTEMS (June 1985 to May 1988)

By

G.S. Poirier

Atomic Energy Control Board
Ottawa, Ontario

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ABSTRACT

The Canadian nuclear power utilities, Hydro Quebec, New Brunswick Electric Power Commission and Ontario Hydro, use thermoluminescent dosimetry systems to perform their own external beta/gamma dosimetry. In order to help ensure that these systems perform satisfactorily, they are subjected to routine quality control testing by their parent organizations. The test results for the period of June 1985 to May 1988 have been analyzed, at the AECB, using the pass criterion which was originally agreed upon by the organizations involved. The present analysis offers a comparison of the performance of the different sites which operate such a service. Finally, recommendations are made in the hope that they will help the organizations in refining their dosimetry.

RESUME

Les organisations qui opèrent les centrales nucléaires au Canada, c'est-à-dire, Hydro Québec, New Brunswick Electric Power Commission et Ontario Hydro, se servent de systèmes de dosimétrie thermoluminescente pour faire leur propre dosimétrie externe beta/gamma. Pour aider à assurer que ces systèmes fonctionnent de façon satisfaisante, ils sont soumis à des essais de contrôle de la qualité par leurs organisations mères. Les résultats des essais pour la période de juin 1985 à mai 1988 ont été analysés, à la CCEA, en se servant du critère qui a été accepté originalement par les organisations impliquées. Les résultats de la présente analyse offrent une comparaison de la performance des différents sites qui opèrent un tel service. Finalement, des recommandations sont faites dans l'espoir que celles-ci aideront aux organisations à raffiner leur dosimétrie.

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1.0 INTRODUCTION

There are five AECB recognized thermoluminescent dosimetry (TLD) services currently in use in Canada: those of Hydro Quebec (HQ), New Brunswick Electrical Power Commission (NBEPC), Ontario Hydro (OH), Atomic Energy of Canada Limited (AECL) and the Bureau of Radiation and Medical Devices (BRMD). In order to help ensure that these external dosimetry services produce results which are within certain limits of statistical acceptability, organizations which operate such services are involved in various quality control (QC) tests. In one such series of tests, dosimeters are exposed to known amounts of ionizing radiation by one group within an organization, and the doses are evaluated (single blind) by another group within the same organization. In the case of the power utilities (i.e., HQ, NBEPC and OH), these QC tests are performed either monthly or biweekly, depending on the organization, and copies of the results are submitted to the AECB. These results are analyzed by AECB staff for each of four sites, i.e., OH has two sites (Pickering and Bruce) and HQ and NBEPC each have one. This report outlines the results of the analysis of three year's worth of data. Results for each site have been letter coded (A to D) to ensure anonymity.

In publishing the results of its analyses, it is the AECB's intent to provide the above services with comparative information and some recommendations which they may find of use in refining their dosimetry.

2.0 STATISTICAL ANALYSIS

2.1 Periods Covered

Data were analyzed for each site for the following periods:

(i) June 1985 to May 1986 (1 year);
(ii) June 1986 to May 1987 (1 year);
(iii) June 1987 to May 1988 (1 year); and
(iv) June 1985 to May 1988 (3 years).

The last period is simply the sum of the preceding three. The periods are specified in the first column of Tables 1 to 4.

2.2 Units and Intervals

The three power utility organizations submit their QC test results in different units, i.e., OH uses mR, HQ uses μSv and NBEPC uses mSv. In order to simplify the analysis of the data, and to preserve anonymity, the unit of mSv is used in this report. In addition, the word "dose" is used in place of "dose equivalent".

For the purpose of analysis, the data were grouped into the following dose intervals:

(i) > 0.0 to 2.0 mSv;
(ii) > 2.0 to 4.0 mSv;
(iii) > 4.0 to 6.0 mSv;
(iv) > 6.0 to 8.0 mSv;
(v) > 8.0 to 10 mSv; and
(vi) > 10 mSv.

These are specified in the second column of the tables.

2.3 Pass Criterion

Acceptability of results was determined using the following criterion, based on the ANSI standard N13.11-1983:

$$|\bar{P}| + 2s \leq L$$

where

$P = 100 \times \left(\frac{X - Y}{Y}\right)$ = percentage difference
X = measured quantity
Y = known quantity
s = sample standard deviations
L = 50.0 for whole body doses $\leq$ 1.0 mSv
L = 30.0 for whole body doses > 1.0 mSv

During a QC test, several dosimeters are simultaneously exposed to the same known amount of radiation; both the average percentage difference $\bar{P}$ and the sample standard deviation s are then calculated. This is repeated for each dose level.

The values of L and the use of 2s (instead of s) are more restrictive than the requirements in the ANSI standard. However, the AECB and participating organizations have agreed to use these values in Canada.

2.4 Parameters Studied

2.4.1 Mean Percentage Differences

The percentage difference, P was calculated for each test badge. Next, the mean value of P, i.e., $\overline{P}$, was calculated for each administered dose, and these were grouped into the dose intervals described in section 2.2 above. Subsequently, the average of the $\overline{P}$ values at each dose interval was calculated and is listed in the tables under "Mean Percentage Differences".

2.4.2 Mean of $|\overline{P}| + 2s$

As in the case of $\overline{P}$, $|\overline{P}| + 2s$ was calculated for each administered dose. Once the administered doses were grouped into dose intervals (see section 2.2 above), the values of $|\overline{P}| + 2s$ were averaged (for each interval). These values can be found in the fourth column of the tables (under $\overline{|\overline{P}| + 2s)}$. Since the magnitude of $|\overline{P}| + 2s$ determines if a test has passed or failed (see section 2.3 above), the average of these values in each dose interval gives a good indication of the dosimetry service's performance in that dose interval.

2.4.3 Tests Failed

As described in section 2.3, QC test results were passed or failed according to the appropriate pass criterion. For each set of $\overline{P}$ and s values, the quantities $|\overline{P}| + 2s$ and $|\overline{P}| + 3s$ were evaluated and compared with the limits in section 2.3. If the appropriate limit was exceeded, the test was counted as a "Fail". The expression $|\overline{P}| + 3s$ was evaluated to complement the $\overline{|\overline{P}| + 2s}$ column as an indication of the performance in each case. Since good performance in one does not ensure good performance in the other. In the tables, the percentage of tests failed in each dose interval is listed under the heading "Fails (%)" and the section headings "2s" and "3s".

3.0 TABLES

Each of Tables 1 to 4 contains the information described in section 2.0 for a given site. In each, the information is separated into three periods: the first three of section 2.1 above. Table 5 contains the information for the overall period (period (iv) in section 2.1) for all four sites and is, therefore, useful for comparison purposes.

4.0 RESULTS

4.1 Site A

4.1.1 Mean Percentage Differences

The mean percentage differences can be seen from Tables 1 and 5 to have remained well within $\pm$ 10% in all dose categories for each period. In fact, the weighted average for $\bar{P}$ for the period from June 1985 to May 1988 was - 0.6%. In addition, there appears to be no identifiable, consistent patterns in the $\bar{P}$ values from one period to the next and from one dose interval to the next.

4.1.2 $\overline{|\bar{P}| + 2s}$

One can see a significant improvement in these values in going from period (i) to period (ii). These better (lower) values are maintained in period (iii) such that the overall period (iv) (Table 5) indicates very good (low) values (i.e., a weighted average of 14.4).

4.1.3 Failures Rates

Failures rates do not appear to occur in an identifiable pattern as one goes from one dose interval to another. In fact, according to Table 5, failure rates seem fairly constant in both the 2s and 3s categories. The maximum failure rate for the 2s category is 8.3% (> 10 mSv dose interval) while in the 3s category, it is 16.0% (> 6.0 - 8.0 mSv dose interval).

4.2 Site B

4.2.1 Mean Percentage Differences

The mean percentage differences can be seen from Tables 2 and 5 to have remained within $\pm$ 10% in all dose categories for each period. The weighted average value of $\overline{P}$ for the overall period is 0.5%. In addition, there appears to be no obvious patterns in the $\overline{P}$ values from one period to the next and from one dose interval to the next.

4.2.2 $\overline{|P|} + 2s$

From Tables 2 and 5, one can see that this value is significantly larger for the lowest dose interval in each period, whereas no obvious pattern can be identified for the other dose categories. One can see from Table 5 that for the lowest dose interval, the site B quantity is the largest of all participants.

4.2.3 Failure Rates

From Table 2, one can see that, in general, failure rates generally tend to be higher in the lower dose intervals in both 2s and 3s categories. This can be seen more clearly in Table 5. The maximum failure rate (Table 5) in the 2s category is 16.7%, whereas in the 3s category it is 52.8% (both for the lowest dose interval).

4.3 Site C

4.3.1 Mean Percentage Differences

The mean percentage differences can be seen from Tables 3 and 5 to have remained well within $\pm$ 10% in all dose categories for each period. The weighted average for $\overline{P}$ for the period from June 1985 to May 1988 was - 0.5%. In addition, no obvious patterns in the $\overline{P}$ values can be identified both as a function of periods and of dose intervals.

4.3.2 $\overline{|P|} + 2s$

Of the four sites, these values are, in general, larger for site C than any of the others. From Table

3, it can be seen that the values are fairly consistent and this is emphasized in Table 5. It can be seen that the highest (poorest) values for site C are consistently those for the lowest dose interval (> 0.0 - 2.0 mSv).

4.3.3 Failure Rates

Failure rates are largest in both the 2s and 3s categories for the lowest dose interval (> 0.0 - 2.0 mSv) for all periods. For the overall period, Table 5 indicates that the highest failure rate for the 2s category is 31.8% and in the 3s category, it is 68.2% (both for the > 0.0 - 2.0 mSv dose interval).

4.4 Site D

4.4.1 Mean Percentage Differences

As can be seen from Table 4 and especially Table 5, this quantity appears to be biased slightly negatively (i.e., all values on Table 5 are negative). The largest value, by far, is for the lowest dose interval (> 0.0 - 2.0 mSv) with a value of $\overline{P}$ = - 22.2%. The weighted average is - 3.5%, which is the largest (negative) weighted average of all.

4.4.2 $\overline{|P|} + 2s$

From Tables 4 and 5, one can see that, with the exception of the lowest dose interval, this quantity is generally quite low. From Table 5, it can be seen that these values remain fairly constant. However, for the lowest dose interval, the value is comparably rather high at 31.6.

4.4.3 Failure Rates

From Tables 4 and 5, it can be seen that the failure rates are quite low. In fact, they are the lowest of the four sites tested in both the 2s and 3s categories. The maximum failure rates are 6.3% in the 2s category and 12.5% in the 3s category.

5.0 NUMBER OF TESTS DONE PER DOSE INTERVAL

Table 6 lists the total number of tests done in each dose interval during the period from June 1985 to May 1988 and its percentage of the total number of tests done in the same period for each site. These values are a good representation of the test distributions for the one-year periods also discussed in this document. Again, to ensure anonymity, the sites have been randomly labelled W, X, Y and Z, the order of which has no relationship to the previous labelling (i.e., A, B, C and D).

6.0 RECOMMENDATIONS

In all cases described above, the following are recommended:

1) Dose Intervals: Over a period of a year, all dose intervals listed in section 2.2 above should be significantly tested as per recommendation #2 below.

2) Number of Tests Per Dose Interval: this quantity should follow the staff dose distributions more closely while adequately testing in all six dose intervals. The yearly distribution of tests could be similar to that suggested in Table 7.

3) In each test (i.e., known exposure value), at least five dosimeters should continue to be used.

4) The larger the total number of tests done each year, the better, but a yearly minimum of 50 tests is recommended (preferably per TLD reader).

5) The use of individual calibration factors for each TLD chip or element is strongly encouraged for all sites.

6) All sites should participate in QC testing through NRC at least one per year. Currently, not all sites are doing this.

7) All sites should continually strive to improve their results by finding and eliminating sources of error.

Table 1
Site A

Period	Dose Interval (mSv)	Mean Percentage Differences $\bar{P}$ (%)	$\lvert\bar{P}\rvert + 2s$	Fails (%) 2s	3s
June 1985	> 0.0 - 2.0	-7.7	20.0	12.5	25.0
- May 1986	> 2.0 - 4.0	-6.0	21.1	20.0	40.0
	> 4.0 - 6.0	-8.1	22.2	16.7	33.3
	> 6.0 - 8.0	-2.8	16.1	0.0	14.3
	> 8.0 - 10.0	-4.9	18.0	20.0	20.0
	> 10.0	-3.2	18.3	10.4	27.1
June 1986	> 0.0 - 2.0	-1.5	9.4	0.0	0.0
- May 1987	> 2.0 - 4.0	0.7	10.6	0.0	0.0
	> 4.0 - 6.0	0.4	12.3	0.0	0.0
	> 6.0 - 8.0	-1.4	11.2	0.0	14.3
	> 8.0 - 10.0	1.4	8.4	0.0	0.0
	> 10.0	-0.1	14.3	9.4	14.1
June 1987	> 0.0 - 2.0	0.9	11.6	7.7	7.7
- May 1988	> 2.0 - 4.0	-0.3	11.8	0.0	7.7
	> 4.0 - 6.0	2.8	12.7	0.0	0.0
	> 6.0 - 8.0	1.3	12.0	9.1	18.2
	> 8.0 - 10.0	1.8	15.8	8.3	8.3
	> 10.0	0.7	13.4	6.1	7.3

Table 2
Site B

Period	Dose Interval (mSv)	Mean Percentage Differences $\bar{P}$ (%)	$\lvert\bar{P}\rvert + 2s$	Fails (%) 2s	3s
June 1985	> 0.0 - 2.0	5.7	49.2	25.0	75.0
- May 1986	> 2.0 - 4.0	-2.9	16.0	0.0	14.3
	> 4.0 - 6.0	-2.4	19.9	0.0	42.9
	> 6.0 - 8.0	-1.7	15.7	0.0	0.0
	> 8.0 - 10.0	-9.2	24.5	0.0	50.0
	> 10.0	-5.2	17.7	0.0	42.9
June 1986	> 0.0 - 2.0	1.4	42.7	16.7	50.0
- May 1987	> 2.0 - 4.0	7.1	23.6	16.7	41.7
	> 4.0 - 6.0	1.9	28.8	16.7	33.3
	> 6.0 - 8.0	-	-	-	-
	> 8.0 - 10.0	4.6	20.6	0.0	33.3
	> 10.0	-0.8	13.7	0.0	0.0
June 1987	> 0.0 - 2.0	-4.2	33.9	8.3	33.3
- May 1988	> 2.0 - 4.0	-0.8	16.2	0.0	8.3
	> 4.0 - 6.0	-1.6	21.9	8.3	33.3
	> 6.0 - 8.0	-	-	-	-
	> 8.0 - 10.0	3.2	16.8	0.0	14.3
	> 10.0	0.7	25.4	20.0	40.0

Table 3
Site C

Period	Dose Interval (mSv)	Mean Percentage Differences $\bar{P}$ (%)	$\lvert\bar{P}\rvert + 2s$	Fails (%) 2s	Fails (%) 3s
June 1985	> 0.0 - 2.0	-3.6	26.4	25.0	62.5
- May 1986	> 2.0 - 4.0	-1.9	20.6	10.0	30.0
	> 4.0 - 6.0	0.2	18.0	0.0	0.0
	> 6.0 - 8.0	-1.7	19.8	0.0	28.6
	> 8.0 - 10.0	2.9	15.0	0.0	0.0
	> 10.0	-1.6	18.2	2.1	20.8
June 1986	> 0.0 - 2.0	1.8	26.1	33.3	66.7
- May 1987	> 2.0 - 4.0	1.4	20.5	20.0	40.0
	> 4.0 - 6.0	3.4	17.2	0.0	25.0
	> 6.0 - 8.0	-3.4	20.7	0.0	33.3
	> 8.0 - 10.0	6.3	23.4	0.0	50.0
	> 10.0	0.2	20.6	16.7	35.4
June 1987	> 0.0 - 2.0	-5.3	26.4	37.5	75.0
- May 1988	> 2.0 - 4.0	2.7	21.8	14.3	42.9
	> 4.0 - 6.0	-3.4	24.7	22.2	33.3
	> 6.0 - 8.0	-1.2	19.5	0.0	50.0
	> 8.0 - 10.0	-0.1	20.6	0.0	57.1
	> 10.0	-0.3	21.6	14.9	48.9

Table 4
Site D

Period	Dose Interval (mSv)	Mean Percentage Differences $\bar{P}$ (%)	$\lvert\bar{P}\rvert + 2s$	Fails (%) 2s	3s
June 1985	> 0.0 - 2.0	-22.2	31.6	0	0
- May 1986	> 2.0 - 4.0	-3.7	12.1	0	0
*	> 4.0 - 6.0	-3.0	8.4	0	0
	> 6.0 - 8.0	-3.1	10.1	0	0
	> 8.0 - 10.0	0.0	9.5	0	0
	> 10.0	-3.7	11.8	0	0
June 1986	> 0.0 - 2.0	-	-	-	-
- May 1987	> 2.0 - 4.0	-3.9	13.6	0.0	5.9
**	> 4.0 - 6.0	-2.4	15.2	10.0	10.0
	> 6.0 - 8.0	-2.9	19.1	0	25.0
	> 8.0 - 10.0	-1.6	15.8	0	0
	> 10.0	-6.8	17.9	0	28.6
June 1987	> 0.0 - 2.0	-	-	-	-
- May 1988	> 2.0 - 4.0	-4.1	14.6	12.0	16.0
***	> 4.0 - 6.0	-2.7	13.5	0.0	0.0
	> 6.0 - 8.0	-1.7	13.6	12.5	12.5
	> 8.0 - 10.0	2.3	7.8	0	0
	> 10.0	1.7	8.5	0	0

*During this period, one test was done at 0.0 mSv.

**During this period, three tests were done at 0.0 mSv.

***During this period, two tests were done at 0.0 mSv.

Table 5
Period: June 1985 to May 1988

Site	Dose Interval (mSv)	Mean Percentage Differences $\bar{P}$ (%)	$\lvert\bar{P}\rvert + 2s$	Fails (%) 2s	Fails (%) 3s
A	> 0.0 - 2.0	-2.1	13.2	6.7	10
	> 2.0 - 4.0	-1.5	14.0	5.6	13.
	> 4.0 - 6.0	0.0	14.4	3.1	6.3
	> 6.0 - 8.0	-0.6	12.9	4.0	16.0
	> 8.0 - 10.0	0.4	13.7	7.7	7.7
	> 10.0	-0.5	14.9	8.3	14.4
B	> 0.0 - 2.0	1.0	41.9	16.7	52.8
	> 2.0 - 4.0	1.8	19.0	6.5	22.6
	> 4.0 - 6.0	-0.4	24.1	9.7	35.5
	> 6.0 - 8.0	-1.7	15.7	0.0	0.0
	> 8.0 - 10.0	2.1	19.4	0.0	26.7
	> 10.0	-2.1	18.5	5.6	27.8
C	> 0.0 - 2.0	-2.8	26.3	31.8	68.2
	> 2.0 - 4.0	0.5	20.9	14.8	37.0
	> 4.0 - 6.0	-0.1	20.3	8.7	21.7
	> 6.0 - 8.0	-2.1	20.0	0.0	36.8
	> 8.0 - 10.0	2.9	20.0	0.0	38.9
	> 10.0	-0.6	20.1	11.2	35.0
D*	> 0.0 - 2.0	-22.2	31.6	0	0
	> 2.0 - 4.0	-3.9	13.5	4.9	8.2
	> 4.0 - 6.0	-2.6	13.1	4.6	4.6
	> 6.0 - 8.0	-2.4	14.1	6.3	12.5
	> 8.0 - 10.0	-0.2	12.2	0	0
	> 10.0	-4.3	13.7	0	10.5

*During this overall period, this organization did six tests at 0.0 mSv.

Table 6
Period: June 1985 to May 1988

Site	Dose Interval (mSv)	Tests Done Per Dose Interval #	%
W	> 0.0 - 2.0	36	27.3
	> 2.0 - 4.0	31	23.5
	> 4.0 - 6.0	31	23.5
	> 6.0 - 8.0	1	0.8
	> 8.0 - 10.0	15	11.4
	> 10.0	18	13.6
X	> 0.0 - 2.0	22	8.7
	> 2.0 - 4.0	27	10.7
	> 4.0 - 6.0	23	9.1
	> 6.0 - 8.0	19	7.6
	> 8.0 - 10.0	18	7.1
	> 10.0	143	56.8
Y	> 0.0 - 2.0	2	1.5
	> 2.0 - 4.0	61	46.2
	> 4.0 - 6.0	22	16.7
	> 6.0 - 8.0	16	12.1
	> 8.0 - 10.0	12	9.1
	> 10.0	19	14.4
Z	> 0.0 - 2.0	30	8.8
	> 2.0 - 4.0	36	10.5
	> 4.0 - 6.0	32	9.3
	> 6.0 - 8.0	25	7.3
	> 8.0 - 10.0	26	7.6
	> 10.0	194	56.6

Table 7

Dose Interval (mSv)	Percentage of the Total Number of Tests (Averaged Over One Year)
> 0.0 - 2.0	30%
> 2.0 - 4.0	20%
> 4.0 - 6.0	15%
> 6.0 - 8.0	15%
> 8.0 - 10.0	10%
> 10.0	10%